

# Error Analysis of Precision Calibrations of Perforated Plate Mesh Materials on a Tuned Reflectometer System

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*This article presents an error analysis of a waveguide technique for precision reflectivity loss measurements of perforated plate mesh materials useful for antenna surfaces, dichroic plates, or RF shields. It is shown that by use of a prescribed experimental procedure, the maximum reflectivity loss measurement error due to imperfect system tuning can typically be kept to less than  $\pm 0.002$  dB.*

## I. Introduction

Perforated plates are useful for such applications as antenna surfaces, dichroic plates, and RF shielding. When the aperture size is small compared to wavelength, it is possible to measure many of the perforated plate RF properties in rectangular waveguides. The waveguide method enables such properties as reflection and transmission coefficients to be measured to a high degree of precision and accuracy.

In a previous article (Ref. 1), it was shown that a waveguide technique can be used to make precision reflectivity loss measurements of perforated plate mesh materials used on antenna surfaces. Overall accuracies of the order of  $\pm 0.005$  dB were achieved by use of a prescribed measurement procedure, a dual-channel tuned reflectometer system, and a high-precision insertion loss test set. This article presents the error analysis equation applicable to the measurement technique.

## II. Measurement Technique

Figure 1 is a block diagram of the tuned-reflectometer system employed for precision reflectivity loss measurements. The system operates on the dual-channel principle and utilizes a high-precision insertion loss test set (Refs. 2 and 3). Comparisons of the reflected power from the mesh sample and that from a reference short-circuit are made on the insertion loss test set.

A major error in mesh reflectivity loss measurements can be caused by the residual internal reflection coefficient  $\Gamma_{2i}$  as seen looking back into the reflectometer system at the measurement plane. This reflection coefficient can be made small by sliding a short-circuit and adjusting tuner B so that the reflectometer output variations become negligibly small (Ref. 4). In general, it is difficult to reduce the peak-to-peak output variation to less than 0.02 dB. However, it is shown in the following error

analysis that although the peak-to-peak output variation of 0.02 dB can result in a maximum error of  $\pm 0.01$  dB, the error on mesh reflectivity loss measurements can generally be reduced to less than  $\pm 0.002$  dB if a flat-plate short is used to establish the measurement reference plane and if the mesh sample is then placed at the same reference plane. If a sample holder is used, one can insert a flat-plate short into the sample holder and use the sample holder-short combination to establish the measurement reference plane.

### III. Error Analysis

If a dual-channel reflectometer system of the type shown in Fig. 1 is linear and has sufficient isolation between test and reference channel couplers, the error analysis simplifies to that for a single-channel reflectometer system such as the one shown in Fig. 2. When a reference offset short and an unknown load are respectively connected to port 2, the equations for the output voltage waves at port 3 are (Ref. 5)

$$b_{3s} = \frac{B\Gamma_s \left(1 + \frac{1}{K\Gamma_s}\right)}{1 - \Gamma_{2i}\Gamma_s} \quad (1)$$

$$b_{3U} = \frac{B\Gamma_U \left(1 + \frac{1}{K\Gamma_U}\right)}{1 - \Gamma_{2i}\Gamma_U} \quad (2)$$

where

$\Gamma_s, \Gamma_U$  = voltage reflection coefficients of the reference offset short and load being calibrated, respectively

$B$  = system constant

$K$  = complex quantity whose magnitude is approximately equal to the directivity ratio ( $\gg 1$ ) of the test channel coupler

$\Gamma_{2i}$  = internal reflection coefficient of the reflectometer system as seen looking into port 2

Measured reflectivity loss relative to the reference short is defined as

$$R'_{dB} = -20 \log_{10} \left| \frac{b_{3U}}{b_{3s}} \right| \quad (3)$$

while the true relative reflectivity loss is

$$R_{dB} = -20 \log_{10} \left| \frac{\Gamma_U}{\Gamma_s} \right| \quad (4)$$

Then, from subtraction of Eq. (4) from Eq. (3) and substitutions of Eqs. (1) and (2), the error equation can be derived as

$$\epsilon_{dB} = 20 \log_{10} \left| \left( \frac{1 + \frac{1}{K\Gamma_s}}{1 + \frac{1}{K\Gamma_U}} \right) \left( \frac{1 - \Gamma_{2i}\Gamma_U}{1 - \Gamma_{2i}\Gamma_s} \right) \right| \quad (5)$$

For mesh calibrations it is valid to assume that

$$|\Gamma_U|, |\Gamma_s| \approx 1$$

and

$$|\Gamma_{2i}|, \frac{1}{|K|} \ll 1$$

Hence, Eq. (5) simplifies to

$$\epsilon_{dB} \approx 20 \log_{10} \left| 1 + (\Gamma_U - \Gamma_s) \left( \frac{1}{K} - \Gamma_{2i} \right) \right| \quad (6)$$

It follows that

$$|\epsilon_{dB}|_{\text{MAX}} \leq 20 \log_{10} \left[ 1 + |\Gamma_U - \Gamma_s| \left( \frac{1}{|K|} + |\Gamma_{2i}| \right) \right] \quad (7)$$

and for  $|\Gamma_U - \Gamma_s| \ll 1$ ,

$$|\epsilon_{dB}|_{\text{MAX}} \leq 8.686 |\Gamma_U - \Gamma_s| \left( \frac{1}{|K|} + |\Gamma_{2i}| \right) \quad (8)$$

In the preparation of test samples it is important that the metallic reflecting surface of the mesh be located at the same distance  $\ell$  from the input flange as the end plate is for the reference offset short (see Fig. 2). Furthermore, the waveguides for the mesh sample holder and reference short should be made from the same material and have the same mechanical dimensions. If these conditions are fulfilled, we may write

$$\Gamma_s \simeq - \left( 1 - \frac{2R_s}{\eta_0} \right) e^{-2\gamma\ell} \quad (9)$$

$$\Gamma_U = S_{11} e^{-2\gamma\ell} \quad (10)$$

where

$R_s$  = surface resistivity of the end plate, ohms/square

$\eta_0 = 120\pi$ , ohms

$S_{11}$  = reflection coefficient of the mesh defined at its metallic reflecting surface

$$\gamma = \alpha + j\beta$$

and  $\alpha$  is the attenuation constant (nepers/m), and  $\beta$  is the phase constant (radians/m).

For typically good reference shorts made from high quality copper, the reflection coefficient magnitudes will be very close to unity (Ref. 6). Hence, we may assume  $\Gamma_s \simeq -e^{-2\gamma l}$ . Substitution into Eq. (8) results in

$$\begin{aligned} |\epsilon_{dB}|_{\text{MAX}} &\leq 8.686 e^{-2\alpha l} |1 + S_{11}| \left( \frac{1}{|K|} + |\Gamma_{2i}| \right) \\ &\leq 8.686 |1 + S_{11}| \left( \frac{1}{|K|} + |\Gamma_{2i}| \right) \end{aligned} \quad (11)$$

For convenience of error study, it is desirable to express the error equation in terms of quantities that are usually measured in the calibration procedure. It was shown by Anson (Ref. 4) that when the reflectometer is tuned for small  $|\Gamma_{2i}|$ , then

$$|\Gamma_{2i}| \approx \frac{M_{dB}}{2(8.686)} \quad (12)$$

where  $M_{dB}$  is the peak-to-peak dB output variation of the signal at port 3 when a movable short is connected to port 2 and then slid. After expressing the directivity ratio  $|K|$  in dB and substituting Eq. (12) into Eq. (11), the error equation becomes

$$|\epsilon_{dB}|_{\text{MAX}} \leq \underbrace{8.686 |1 + S_{11}| 10^{-K_{dB}/20}}_{\text{Directivity error term}} + \underbrace{\frac{M_{dB}}{2} |1 + S_{11}|}_{\Gamma_{2i} \text{ Error term}} \quad (13)$$

In the above it can be seen that the directivity error term is generally small because  $K_{dB}$  is typically 70 dB or greater. In addition, since most good meshes behave almost like a short-circuit load (i.e.,  $S_{11} \simeq -1$ ), it can also be seen that the error due to either term will be small.

Typical good meshes will have reflectivity loss less than 0.2 dB and phase angles within 10 deg of that for a short-circuit. These properties can be described mathematically as

$$0.977 \leq |S_{11}| \leq 1.0$$

$$170^\circ \leq \psi_{11} \leq 180^\circ$$

For mesh materials having these properties, Fig. 3 shows the maximum error curves based on Eq. (13) and typical values of  $K_{dB}$  and  $M_{dB}$ . For example, when a reflectometer system is tuned for 70 dB directivity and 0.02 dB peak-to-peak output variation when a sliding short is slid, the maximum error on reflectivity loss measurement is  $\pm 0.0022$  dB. These are typical system tuning values that are easy to obtain in practice. For more accuracy the reflectometer system can be tuned to give smaller residual errors.

#### IV. Conclusions

An error analysis has been presented to show that by use of a prescribed measurement procedure, reflectivity loss measurement errors due to imperfect system tuning can be reduced to about  $\pm 0.002$  dB. To achieve the improved accuracy using this procedure, it is also required that (1) the mesh sample reflectivity loss be less than 0.2 dB, (2) the mesh reflection coefficient phase angle be within 10 deg of the phase angle of the reference flat-plate short, and (3) the directivity of the test channel coupler be tuned to at least 70 dB.

## References

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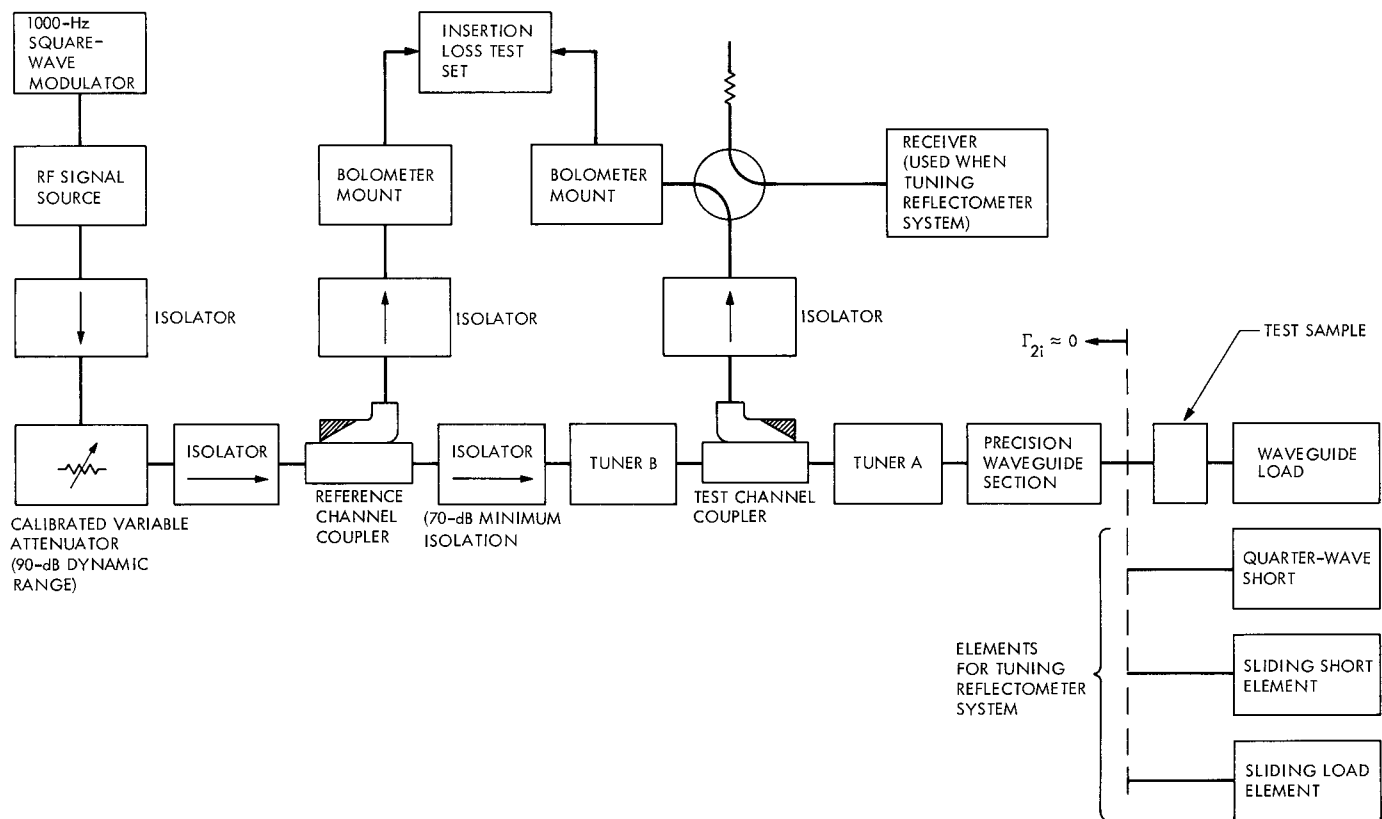


Fig. 1. Block diagram of waveguide system for mesh reflectivity measurements

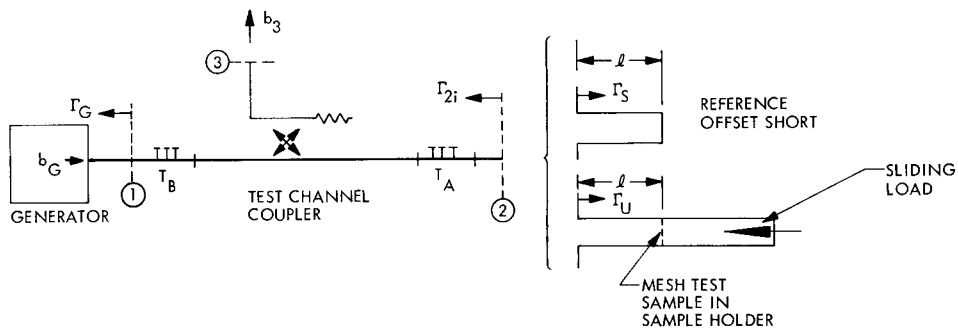


Fig. 2. Simplified block diagram of reflectometer system for error analysis

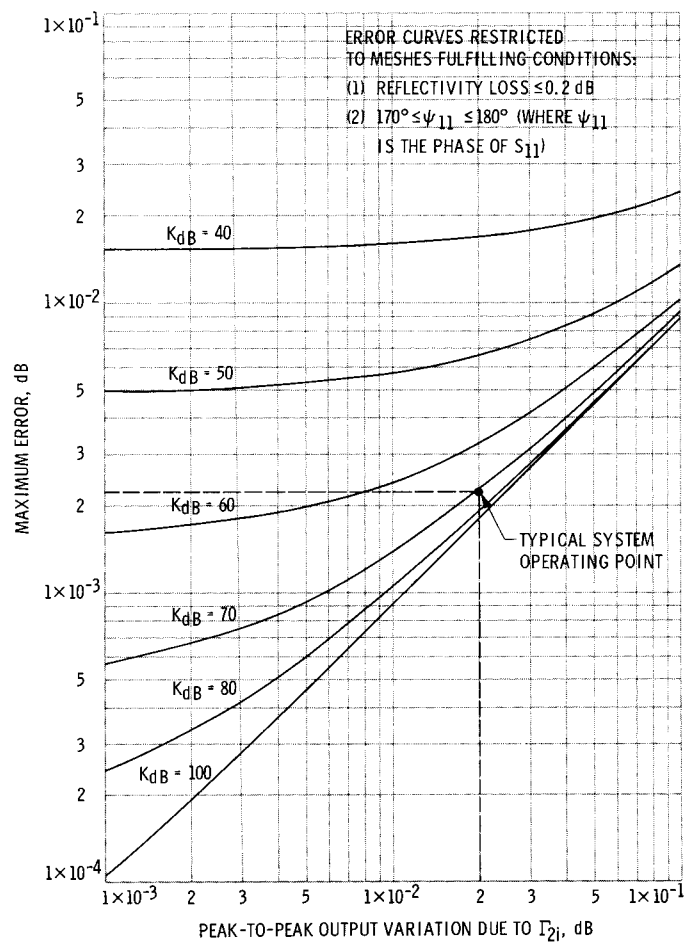


Fig. 3. Maximum error due to residual tuning errors on measurement of reflectivity losses of meshes or short-circuits